INDICES FOR ASSESSMENT AND MONITORING OF LARGE MAMMALS WITHIN AN ADAPTIVE MANAGEMENT FRAMEWORK

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Abstract. Many development projects intended to exploit natural resources are occurring in fragile ecosystems, and therefore the need for sound biodiversity assessment and monitoring programs is growing. Large mammals are important components of these fragile ecosystems, yet there are few strategies that attempt to assess and monitor entire large mammal communities in relation to development projects. We propose the use of two indices applied within a framework of adaptive management. An occurrence index assesses the composition and distribution of large mammals at a site, and an abundance index monitors the abundance of large mammals over time in relation to development. We discuss the design, applicability and effectiveness of these indices based on our experience with a natural gas development project in the Amazon forests of southeastern Peru.

Keywords: adaptive management, assessment, development, large mammals, monitoring, tropical forests

1. Introduction

The need for sound biodiversity assessment and monitoring programs is growing (Goldsmith, 1991; Spellerberg, 1992). Increasing demands on Earth's natural resources are leading to development projects in nearly every corner of the globe. These development projects inevitably alter ecosystems at many scales and may be leading to loss of species richness and viability (Myers, 1986; Whitmore, 1997). Presently, we do not know what effect this loss of biodiversity will have on the health of the planet; thus, there is a need for a better understanding of biodiversity, how it changes over time and appropriate management of ecosystems.

In 1996, Shell Prospecting and Development Peru (SPDP) reestablished a natural gas exploration project in the Lower Urubamba region of southeastern Peru. SPDP planned to drill four well sites, construct flow lines, a gas plant and a pipeline (Dallmeier and Alonso, 1997). The Smithsonian Institution's Monitoring and Assessment of Biodiversity program (SI/MAB) entered into a cooperative venture with SPDP to integrate science and conservation with exploration and development of natural gas resources. Together, SI/MAB and SPDP established a large-scale, multi-taxa biodiversity assessment and monitoring program for the Lower Urubamba forests (Dallmeier and Alonso, 1997; Alonso and Dallmeier, 1998, 1999). Here, we discuss the ecological importance of large mammals and our

Environmental Monitoring and Assessment **76:** 105–123, 2002.

approach towards assessment and monitoring of communities of large mammals in a previously unexplored tropical forest within an adaptive management framework (Holling, 1978). We considered large mammals to be all members of the Orders Marsupialia, Xenarthra, Primates, Carnivora, Perissodactyla, Artiodactyla and Lagomorpha and the families Sciuridae, Erethizontidae, Dinomyidae and Dasyproctidae of the Order Rodentia.

1.1. DIVERSITY, ECOLOGY AND CONSERVATION OF LARGE MAMMALS

There are 4629 extant mammal species on Earth (Wilson and Reeder, 1993), and the diversity of adaptations and behaviors they exhibit is astounding. Mammals are extremely important to the proper functioning of ecosystems. They share responsibility for pollinating plants (Carthew and Goldingay, 1997; Fleming and Sosa, 1994; Janson *et al.*, 1981) and distributing seeds (Levey *et al.*, 1994), they are both predator and prey (Nowak, 1991) and they can have immense effects on the structure and composition of vegetation (Sinclair and Norton-Griffiths, 1979; McInnes *et al.*, 1992; Sinclair and Arcese, 1995), plant productivity (Frank and McNaughton, 1993) and nutrient cycling (Pastor *et al.*, 1993). They also fulfill roles for humans such as clothing, food and spiritual values.

These familiar animals may be experiencing greater population declines than any of the other vertebrate groups (IUCN, 1996). Of the known species of mammals, 25% are threatened, 11% are endangered, 4% are critically endangered and nearly 2% (86) of the known modern-day mammals have gone extinct in the last 400 years (IUCN, 1996). The loss of mammalian diversity could alter ecosystems in ways we do not yet comprehend. Therefore, it is imperative that biologists develop appropriate assessment and monitoring protocols for mammals.

Sampling methods for assessing the distribution and abundance of mammals are well standardized and widely accepted (see Wilson *et al.*, 1996). Most of the methods for larger mammals have been developed for conspicuous, economically important, well-known species that often live in open savanna or grassland areas where they are easily viewed. However, many mammal species, especially those indigenous to tropical forests, are cryptic and discrete and inhabit areas that are not easily accessible. Large mammals are also extremely mobile, they often have large home ranges and, when disturbed, they may travel long distances to find new home ranges (Mace and Waller, 1997; Andreka *et al.*, 1999), thus forcing researchers to cover large areas in search of a few individuals. These traits make it challenging to locate, count and monitor mammals in tropical forests and necessitates creative, flexible methods to assess and monitor populations and communities of mammals.

Observing and counting animals is a definitive way of determining the presence and abundance of different species. But direct observation of mammals in a tropical rainforest is difficult because of dense vegetation, high canopies and nocturnal habits and because the animals sometimes deliberately avoid people (Eisenberg and Thorington, 1973). Many mammals do leave unambiguous signs that verify presence and relate to abundance (Wemmer *et al.*, 1996), and this evidence can be collected and used to develop indices of presence and abundance (Seber, 1982). In the United States where biologists have been studying economically valuable animals (game species and furbearers) for nearly 70 years, indices have been developed that verify presence and measure population trends through time (Conner *et al.*, 1983). However, to relate indices of abundance with actual abundance requires knowledge of the natural history of the species in question (Caughley, 1977). Such information is often incomplete in tropical forests. Indices for monitoring assemblages of large mammals in tropical forests should verify presence without physical collections, indicate abundance, be easy to use, be standardized for comparisons, be flexible and provide information on a wide range of habitat niches and behaviors.

2. Study Area

The study took place in the lowland tropical forests of Amazonian Peru. We sampled throughout the Lower Urubamba region near the junction of the Urubamba, Camisea and Cashiriari rivers. This region is at the western edge of Amazonia along the base of the Andes Mountains in an area of remarkable biological diversity (Gentry, 1988, 1990; Voss and Emmons, 1996). We assessed mammals over an area of approximately 600 km^2 centered at 12°S latitude and 72°W longitude. Dallmeier and Alonso (1997) provide a detailed description of the study area.

In general, the region is lowland tropical rainforest, and the sampling sites were located in mature forest (Comiskey *et al.*, 2001). We investigated four sites, all of which were characterized by terrain of steeply sloping hills and large, flat plateaus. At two sites, the arborescent bamboo, *Guadua sarcocarpa*, represented a major component of the habitat (Comiskey *et al.*, 2001). Elevation varied from approximately 300 to 600 meters (m). Mean annual temperature was about 24 °C and varied little throughout the year. The relative humidity typically exceeded 80%. Mean annual rainfall ranged from 3000 to 3500 millimeters (mm), and there were distinct wet (October through April) and dry seasons (May through September) (Dallmeier and Alonso, 1997).

3. The Assessment and Monitoring Program

Biodiversity assessments and monitoring are typically conducted within a framework of adaptive management (Holling, 1978; Walters, 1986; Hilborn, 1992). When working in an ecosystem where many parameters such as the number and type of species present or sufficient understanding of inter-specific relationships are unknown, management strategies must be continually monitored to evaluate their effectiveness (Comiskey *et al.*, 2000). Adaptive management is a cyclical process in which participants build continually on previous learning experiences to improve management policies and practices. The 4 steps in an adaptive management program are: (1) design management and monitoring objectives, (2) implement management, (3) assessment and monitoring and (4) evaluation and decision making (Holling, 1978; Comiskey *et al.*, 2000).

3.1. MANAGEMENT AND MONITORING OBJECTIVES

Our management objective was to minimize the impacts of the natural gas exploration project on biodiversity in the region. Our monitoring objectives were to: (1) obtain baseline information regarding the status and distribution of large mammals, (2) design monitoring protocols for large mammals and (3) note changes in populations brought about by development.

3.2. ASSESSMENT

We chose the mammal assessment sites based on proximity to 4 one-hectare (ha) vegetation monitoring plots established by SI/MAB (Dallmeier and Alonso, 1997; Alonso and Dallmeier, 1998, 1999; Comiskey *et al.*, 2001) and to 4 gas drilling sites established by SPDP-San Martin-3 (Sanm-3), Cashiriari-2 (Cash-2), Cashiriari-3 (Cash-3) and Pagoreni (Pag). This allowed us to relate the composition of the mammal community to detailed habitat descriptions and to areas of the forest under development. We conducted the study during the dry season at Sanm-3 (May 1997), Cash-2 (June 1997) and Pag (April 1998) and during the rainy season at Cash-3 (November 1997). We spent 4 weeks at each site.

3.2.1. *Occurrence Index*

We collected data along subjectively placed survey routes (transects) cut through the forest at each site across a variety of microhabitats (hilltops, valleys, streams, etc.). The selection and extent of transects was intended to maximize the number of species encountered. Topography and our ability to penetrate dense vegetation affected trail lengths, which totaled 6 kilometers (km) at Sanm-3, 8.5 km at Cash-2, 5 km at Cash-3 and 4.5 km at Pag. Transect width extended 2 m on either side.

We used five survey procedures to assess the large mammal community (Wilson *et al.*, 1996): direct observation of animals, aural identification of animal vocalizations, scent-post surveys (Linhart and Knowlton, 1975), searching for mammalian sign (Wemmer *et al.*, 1996) and trapping. We spent 7 hours per day investigating the transects and recording data. Throughout the study, our teams consisted of experienced staff and several guides from the local community. The guides were hunters, and their skills contributed a wealth of local natural history knowledge that provided the necessary foundation for making this assessment successful.

3.2.1.1. *Direct Observations.* We observed animals directly while walking the transects. We also used TrailMaster® infrared trail monitors and Olympus Infinity Mini DLX cameras to remotely observe animals (Carthew, 1991; Kucera and Barrett, 1993).

3.2.1.2. *Mammal Vocalizations.* We identified animals through vocalizations heard fortuitously. In addition, the guides were adept at mimicking the calls of many local mammals, which allowed us to elicit responses or lure animals into a position for visual identification.

3.2.1.3. *Scent-post Surveys.* We modified the scent-post survey method described by Linhart and Knowlton (1975). Rather than a distance-defined transect route, we placed scent stations at optimum locations to record the maximum number of species. Locations selected included the edges of ecotones, intersections of human-made and wildlife trails, saddles between hill peaks, stream intersections and where geological features concentrated mammal travel lanes. At each sampling site, we set 1 to 4 circular scent stations 1 m in diameter, spaced 5 m apart. In the center of each station, we placed a cotton swab that contained commercial furbearer trapping lure. We experimented with a variety of Carman-brand lures (Carman's Superior Animal Lures, RR 2, Box 182, New Milford, PA 18834, U.S.A.). We visited scent post stations daily and identified and recorded any tracks present. Stations were swept clean of tracks every day, and the lures were replaced every 4 days. We established 36 stations at Sanm-3, 28 at Cash-2, 30 at Cash-3 and 32 at Pag.

3.2.1.4. *Mammalian Signs.* We searched for signs of large mammals along the transects. The signs included fresh tracks; feces; lavatory stations; feeding, digging or territorial markings; animal parts; and other tangible evidence that mammal species were present.

3.2.1.5. *Trapping.* We set live traps along the transects in optimum locations to record the maximum number of species. We emphasized non-lethal sampling methods for the following reasons: (1) large mammals are used as food resources by local communities; (2) recruitment is relatively low in large mammals, thus removing individuals may have a significant impact on populations; (3) collection permits were difficult to obtain; (4) most well-known large mammals are common in collections, museums and zoos; and (5) large-mammal collections require complicated logistical support and extensive time for preservation of skins and use of specimens. We used 4 sizes of adaptable Gregerson brand snares (0, 1, 2 and #4), selected for their versatility. While these snares can be used as humane killing devices or hair collectors, we modified them for use as capture-and-release devices. Snare placement, height off the ground, loop size, and sensitivity provided various elements of evidence about species movement on trails and around scents and baits. In addition, we set 4 #1 1/2 rubber padded-jaw traps, 6 #1/2 regular jaw leghold traps (Woodstream Corporation, Lititz, PA 17543, U.S.A.) and 1 #1 1/2 padded-

TABLE I

Information recorded on standardized daily log forms

Location	Time of observation
General survey conditions	Number and sex of individuals (if observed)
Observer	Behavior (if observed)
Weather	Lure/attractant
Habitat type	Duplicate record (yes/no)
Species	Hours spent/day
Evidence type	Km traveled/day
Survey procedure	

jaw trap (Butera Manufacturing Inc, 361 1st Street, East Lake, OH 44095, U.S.A.) in conjunction with scent-post stations for 10 days at Cash-3.

The basic unit upon which the data were focused was called a ‘mammal event’, which occurred each time an observer recorded a sign, sound, sighting or other evidence of large mammal presence by any of the procedures described above. Mammal events included direct data (samples and observations) and indirect data (tracks, feces, hair, bone, feeding characteristics, beds, dens, nests, trails, vocalizations and odors). We also questioned local people about the species present by showing them photographs of neotropical mammals. We eliminated duplication of serial data; that is, 2 or more articles of the same type of evidence from presumably the same individual, based on comparisons of size, shape or location of the evidence. We created a daily log report form as a standardized reporting tool for use by researchers (Table I). Tangible evidence was collected, identified, photographed and stored whenever possible.

To verify presence, we developed an occurrence index. The occurrence index provided a confirmed species list based on accumulated evidence from various survey procedures. When the accumulated points of evidence reached a threshold, we concluded the species was present at the site.

We calculated the occurrence index from evidence gathered from the 5 mammal survey procedures. Each type of mammal event was assigned a value based on a point system that reflected the quality of that piece of evidence (Table II). We segregated types of evidence into 3 categories – unambiguous evidence, high-quality evidence and low-quality evidence (Table II). Unambiguous evidence refers to a species observed or collected, including any part of the individual such as a complete skull that would lead to certain identification. High-quality evidence refers to evidence that is characteristic of a species but may be distorted in some manner or similar to evidence left by other species. For example, the tracks of an ocelot (*Leopardus pardalis*) and a margay (*L. wiedii*) are definitive, but similar. The substrate where these tracks occur may distort them so that researchers are unable

TABLE II

Point values for various types of evidence used to calculate the occurrence index

Type of evidence	Point value
Unambiguous evidence	
Species collected	10
Species observed	10
High quality evidence	
Bone[a]	5
Hair	5
Identification by local residents[b]	5
Tracks	5
Vocalizations and odors	5
Low quality evidence	
Beds, dens, nest, trails	4
Feces (scat)	4
Feeding characteristics	4

[a] Does not include a complete skull or other skeletal evidence that would permit unambiguous identification.

[b] We questioned local people about the species present by showing them photographs of neotropical mammals.

to differentiate the two. Low-quality evidence refers to evidence that is suggestive but not characteristic of a species.

We calculated the index by summing the accumulated points recorded for each species. Species presence was established when the points totaled 10. Mammal events describing unambiguous evidence qualified as verification of presence with no additional evidence required. We assigned unambiguous evidence a value of 10, and this then defined the threshold value. Verification of presence based on high-quality indirect evidence required at least 2 mammal events of different types for the same species (Table II). Verification of presence based on low-quality indirect evidence required at least 3 mammal events of different types (Table II). Each mammal event was counted only once for the occurrence index, even though that specimen type may have been collected more than one time.

An example of the occurrence index (Table III), based on data for the Brazilian tapir (*Tapirus terrestris*), shows the various types of evidence collected, the associated point values and how this data led to a positive listing of presence at

TABLE III

Example of the occurrence index and the abundance index; data are for the Brazilian tapir (*Tapirus terrestris*)

Type of evidence	Occurrence index	Number of observations[a]	Abundance index (occurrence points x number of observations)
Species collected	0	0	0
Species observed	10	1	10
Tracks	5	7	35
Feces (scat)	4	3	12
Hair	0	0	0
Bone	0	0	0
Feeding characteristics	4	1	4
Beds, dens, nest, trails	4	3	12
Vocalizations and odors	0	0	0
Questioning of local residents[b]	5	N/A	N/A
Index value	32		73

[a] An artificial set of data used for illustrative purposes.

[b] We questioned local people about the species present by showing them photographs of neotropical mammals.

Sanm-3. The value for the Brazilian tapir (32) far exceeded the threshold value, so we concluded that tapirs were present. In this case, tapir presence was confirmed because an individual was observed, and such unambiguous evidence requires no additional support. However, if we had not observed a tapir, there was enough additional evidence, including tracks (value of 5) and claims by local residents (value of 5) to conclude that tapirs were present (total of 10 for the 2 mammal events).

It is often possible and many times probable that some kinds of indirect evidence valued at less than 10 may, in fact, be unambiguous verification of a species presence and should rate at least 10; examples include jaguar (*Panthera onca*) tracks and howler monkey (*Alouatta seniculus*) calls. The scale we used reflected our skills and confidence at the time of the study. Other researchers with different skills, experiences and abilities may consider a species as present based on index values that total less than 10.

3.2.2. *Assessment Results*

We compiled a list of species expected to occur at the 4 sites, using range maps and distribution descriptions (Emmons and Feer, 1990; Pacheco and Vivar, 1996; Guerrero and Zeballos, 1996), other mammal studies in the area (Solari *et al.*, 2001) and interviews with local inhabitants. Eighty-one species of large mammals

TABLE IV

List of actual and potential large mammal species at four sites in the Lower Urubamba region, Peru (includes all species expected to occur based on range maps and distribution descriptions from Emmons and Feer (1990), Pacheco and Vivar (1996), Guerrero and Zeballos (1996) and interviews with local inhabitants)[1]

Species	San Martin-3		Cashiriari-2		Cashiriari-3		Pagoreni		Manu
	OI	ET	OI	ET	OI	ET	OI	ET	
Didelphimorphia									
Didelphidae									
Caluromys lanatus	NC	e	NC	e	C[a]	e	NC	e	X
Caluromys philander	NC	e	NC	e	NC	e	NC	e	
Caluromysiops irrupta	NC	e	NC	e	C[a]	e	NC		X
Chironectes minimus	24	b, e, f, j	NC	e	10	e, f	NC	e	
Didelphis albiventris	NC		NC		NC		NC	e	
Didelphis marsupialis	35	a, b, e, f, j	10	e, g	10	e, f	20	a, e, g	X
Gracilinanus kalinowskii	NC		NC		C[a]		NC		
Marmosa cf. *agilis*	C[a]		C[a]		C[a]		C[a]		X
Marmosa andersoni	C[a]		NC		C[a]		NC		
Marmosa demerarae	NC		C[a]		NC		NC		
Didelphidae (continued)									
Marmosamurina	NC		NC		C[a]		C[a]		X
Marmosa noctivaga	C[a]		C[a]		C[a]		C[a]		X
Marmosaparvidens	NC		C[a]		NC		NC		X
Marmosaregina	C[a]		NC		C[a]		C[a]		X
Metachirus nudicaudatus	C[a,b]	e	C[a]	e	NC	e	C[a]	e	X
Monodelphis adusta	NC		NC		C[a]		NC		
Monodelphisbrevicaudata	C[a]		NC		NC		NC		X
Monodelphisemiliae	C[a]		NC		C[a]		NC		
Philanderopossum	C[a]	e	NC	e	C[a]	e	15	b, e	X
Xenarthra									
Bradypodidae									
Bradypus variegatus	15	b, e	NC	e	NC	e	NC	e	X
Dasypodidae									
Cabassous unicinctus	NC	e	NC	e	NC	e	NC	e	

[1] Values represent the occurrence index value (OI). Only values that confirm presence ($\geq$10) are shown. 'NC' represents not confirmed. 'C' represents species confirmed as present at the site based on data obtained in other studies. Evidence type (ET) represents the types of evidence that led to confirmation of occurrence: a = species collected, b = species observed, c = bones, d = hair, e = identification by local residents, f = foot prints (tracks), g = vocalization or odor, h = bed, den, nest or trail, i = feces, j = feeding sign and a blank space represents no evidence collected. Forty-five species were confirmed in this study, and an additional 19 species were confirmed in other studies. 'Manu' represents species that were also recorded in Manu National Park, Peru (Pacheco *et al.*, 1993, Voss and Emmons, 1996). Nomenclature based on Nowak, 1991, except for the ordinal name Didelphimorphia (Wilson and Reeder, 1993).

[a] = Confirmed by Solari *et al.* (2001). [b] = Confirmed by Juan José Rodriguez (unpublished data).

TABLE IV

(continued)

Species	San Martin-3		Cashiriari-2		Cashiriari-3		Pagoreni		Manu
	OI	ET	OI	ET	OI	ET	OI	ET	
Dasypus kappleri	NC	e	NC	e	NC	e	NC	e	
Dasypus novemcinctus	13	e, h, j	18	e, f, h, i	14	e, f, h	28	b, e, f, h, j	X
Dasypus septemcinctus	NC	e	NC	e	NC	e	NC	e	
Euphractus sexcinctus	NC	e	NC	e	NC	e	13	e, h, j	
Priodontes maximus	NC	e	NC	e	10	e, f	13	e, h, j	X
Megalonychidae									
Choloepus didactylus	NC	e	15	c, d, e	NC	e	NC	e	
Choloepus hoffmanni	NC	e	NC	e	15	a, e	NC	e	X
Myrmecophagidae									
Cyclopes didactylus	NC	e	NC	e	NC	e	NC	e	X
Myrmecophaga tridactyla	NC	e, j	NC	e	NC	e	13	e, h, j	X
Tamandua tetradactyla	NC	e, j	NC	e	10	e, f	NC	e	X
Primates									
Callitrichidae									
Cebuella pygmaea	NC	e	NC	e	NC	e	NC	e	X
Saguinus mystax	NC	e	20	b, e, g	NC	e	NC	e	
Saguinus fuscicollis	NC	e	20	b, e, g	NC	e	NC	e	X
Saguinus imperator	15	b, e	NC	e	15	b, e	NC	e	X
Cebidae									
Alouatta seniculus	20	b, e, g	15	b, e	20	b, e, g	20	b, e, g	X
Aotus sp.	NC	e	NC	e	15	b, e	20	b, e, g	
Ateles paniscus chemek	20	b, e, g	NC	e	NC	e	10	e, g	X
Cacajao calvus	NC	e	NC	e	NC	e	NC	e	
Callicebus moloch brunneus	NC	e	NC	e	15	b, e	NC	e	X
Cebidae (continued)									
Cebus albifrons	20	b, e, g	20	b, e, g	15	b, e	15	b, g	X
Cebus apella	20	b, e, g	20	b, e, g	15	b, e	NC	e	X
Lagothrix lagotricha	NC	e	NC	e	15	b, e	NC	e	X
Pithecia monachus	NC	e	NC	e	NC	e	15	b, e	
Saimiri sciureus boliviensis	20	b, e, g	NC	e	15	b, e	NC	e	X
Carnivora									
Canidae									
Atelocynus microtis	NC	e	14	e, f, h	NC	e	NC	e	X
Speothos venaticus	20	b, e, f	NC	e	NC	e	10	e, f	

TABLE IV
(continued)

Species	San Martin-3		Cashiriari-2		Cashiriari-3		Pagoreni		Manu
	OI	ET	OI	ET	OI	ET	OI	ET	
Felidae									
Felis concolor	NC	e	23	e, f, g, h, i	NC	e	NC	e	X
Felis pardalis	18	e, f, h, i	24	b, e, f, h	18	e, f, i, j	14	e, f, i	X
Felis tigrina	C[b]	e	NC	e	C[b]	e	NC	e	
Felis wiedii	10	e, f	10	e, f	NC	e	NC	e	X
Felis yagouaroundi	NC	e	NC	e	NC	e	NC	e	X
Panthera onca	NC	e, h	23	e, f, g, h, i	14	e, f, h	14	e, f, h	X
Mustelidae									
Eira barbara	14	e, f, h	18	c, e, i, j, h	24	b, e, f, j	NC	e	X
Galictis vittata	NC		NC		C[b]		NC		X
Lutra longicaudis	NC	e	NC	e	NC	e	14	e, f, h	X
Mustela africana	NC	e	NC	e	NC	e	NC	e	
Mustela frenata	NC	e	NC	e	NC	e	NC	e	
Pteronura brasiliensis	NC	e	NC	e	NC	e	NC	e	X
Procyonidae									
Bassaricyon gabbii	NC	e	NC	e	NC	e	NC	e	X
Nasua nasua	14	e, f, j	10	e, f	NC	e	14	e, f, j	X
Potos flavus	NC	e	10	c, e	NC	e	NC	e	X
Procyon cancrivorus	10	e, f	14	e, f, j	14	e, f, j	14	e, f, h	X
Perissodactyla									
Tapiridae									
Tapirus terrestris	32	b, e, f, h, i, j	14	e, f, h	22	e, f, h, i, j	14	e, f, h	X
Artiodactyla									
Cervidae									
Mazama americana	29	b, e, f, g, h	29	b, d, e, f, h	24	b, e, f, h	15	e, f, g	X
Mazama gouazoubira	NC	e	NC	e	NC	e	NC	e	X
Odocoileus virginianus	NC	e	C[b]		C[b]	e	NC	e	
Tayassuidae									
Tayassupecari	10	e, f	NC	e	NC	e	NC	e	X
Tayassu tajacu	33	b, e, f, g, h, j	29	c, d, e, f, g, j	33	b, e, f, g, h, j	18	e, f, h, j	X
Rodentia									
Dinomyidae									
Dinomys branickii	NC	e	NC	e	NC	e	14	e, f, j	X

TABLE IV
(continued)

Species	San Martin-3		Cashiriari-2		Cashiriari-3		Pagoreni		Manu
	OI	ET	OI	ET	OI	ET	OI	ET	
Dasyproctidae									
Agouti paca	14	e, f, h	14	e, f, h	18	e, f, h, j	18	e, f, h, j	X
Dasyprocta punctata variegata	28	a, e, f, h, j	34	b, c, e, f, g, j	18	e, f, h, j	14	e, f, h	X
Myoprocta acouchy	14	e, f, j	14	e, f, j	24	b, e, f, h	14	e, f, j	X
Erethizontidae									
Coendou cf. *bicolor*	NC		NC		NC		C[b]		X
Coendouprehensilis	NC	e, j	NC	e, j	13	e, h, j	NC	e	
Hydrochaeridae									
Hydrochaeris hydrochaeris	NC	e	NC	e	NC	e	NC	e	X
Sciuridae									
Microsciurus flaviventer	20	b, e, g	20	b, e, g	15	b, e	19	b, e, j	X
Sciurus cf. *sanborni*	NC		NC		C[b]		NC		
Sciurus sp.	NC		NC		NC		C[b]		
Sciurus spadiceus	10	e, g	20	b, e, g	15	b, e	15	b, e	X
Lagomorpha									
Leporidae									
Sylvilagus brasiliensis	24	b, e, f, j	24	b, e, f, j	24	b, e, f, i	10	e, f	X
Total species (this study)	26		25		27		26		
Total species from all studies	36		31		43		34		

were considered potentially present at the 4 sites. We confirmed the presence of 46 species (58% of the potential list); 26 species at Sanm-3, 25 at Cash-2, 27 at Cash-3 and 26 at Pag (Table IV). The richness and composition of large mammals in the study region were similar to 4 other sites in southeastern Peru (Voss and Emmons, 1996). Nearby Manu National Park, one of the richest mammal faunas in the neotropics, claims 60 species of large mammals after 21 years of investigation (Voss and Emmons, 1996). The total number of large mammal species in the Lower Urubamba region based on this study, Solari *et al.* (2001) and additional studies conducted by one of authors, J. J. Rodriguez (unpublished data) is 64 species (Table IV). Of the 46 species confirmed in this study, 38 also occur in Manu (Table IV; Pacheco *et al.*, 1993; Voss and Emmons, 1996). This demonstrates that intensive collection of data through a variety of techniques provides ample data in a relatively short amount of time and is an effective strategy for assessing large mammal communities in tropical forests.

3.2.3. *Effectiveness of the Data Collection Procedures*

Interviews with local people provided an enormous amount of information. Every species confirmed at the 4 sites was identified by local people as being present at the site prior to the actual field work (Table IV), and we recommend that all assessments of large mammals be preceded by interviews with local inhabitants. The remaining 5 survey procedures were useful to varying degrees, each with its own strengths and weaknesses. The most effective in confirming species presence was the investigation of mammalian signs, a procedure that contributed to the confirmation of 30 species (Table IV). But signs were not effective in collecting information on arboreal species. Of the 16 species for which we found no signs, 15 were arboreal species. They included all 12 confirmed primates, a brown-throated three-toed sloth (*Bradypus variegatus*) and a southern Amazon red squirrel (*Sciurus spadiceus*; Table IV). Ultimately, the success of this procedure lies in the ability of the researcher to locate and interpret the signs (Wemmer *et al.*, 1996). The scavengers and rain that are typical of a rainforest ensured that evidence such as feces, body parts and physical disturbances was of recent origin.

Scent-post surveys proved effective in collecting high-quality evidence quickly and at low cost (US$0.10 per post). The 126 scent stations resulted in 138 track observations: 35 at Sanm-3, 43 at Cash-2, 30 at Cash-3 and 30 at Pag. Carnivores, often the most elusive species, responded most often to the scent-post stations. As with mammalian signs, we did not generally confirm the presence of arboreal species with this survey procedure. We did observe that some animals were neophobic and required 3 to 4 days to become acclimated to foreign odors. The following types of Carman lures evoked the most responses: Carman's Canine Call Lure, Pro's Choice, Bobcat Gland Lure, Trophy Deer Lure and Mega Musk. The following lures elicited many responses from small rodents, but not the larger mammals targeted in this study: Wind River Beaver Lure, Magna Gland Lure, Silent Partner, Trails End, Raccoon #1, Still Water, Three Rivers, Midnight and Red Fox Gland Lure.

Aural identification of mammalian vocalizations was effective for primates and felids (Table IV). The mimicry skills of the guides elicited either vocal responses by many mammals or encouraged the mammals to approach us so that we could confirm their presence visually. As an example, on 10 out of 12 occasions, monkeys responded to mimicked vocalizations by approaching us, which allowed us to verify the species presence by observation. If qualified guides are not available, vocalizations of various mammals can be recorded and played back on a cassette tape player. We observed or heard the ocelot, jaguar, collared peccary (*Tayassu tajacu*), black-chested mustached tamarin (*Saguinas mystax*), dusky titi monkey (*Callicebus moloch brunneus*), common squirrel monkey (*Saimiri sciureus boliviensis*), brown capuchin monkey (*Cebus apella*), white-fronted capuchin monkey (*C. al-*

bifrons), black spider monkey (*Ateles paniscus chemek*) and red howler monkey using various vocalization types and procedures.

Direct observations provided unambiguous evidence confirming a species presence. We observed 27 species during the study (Table IV). The strategy was most effective for Primates; we observed 12 such species. Normally, observations were easiest for arboreal species (Primates, sloths and squirrels) and larger terrestrial herbivores such as red brocket deer (*Mazama americana*) and collared peccaries (Table IV). We observed few Carnivores, and those were mostly chance encounters. Direct observations require perceptiveness, hours of field work and a bit of serendipity (Wemmer *et al.*, 1996). As a general biodiversity assessment and monitoring tool, this survey technique offers a low return on the time invested if it is used alone. Because direct observations can be conducted simultaneously with other survey procedures with little additional effort, however, they are a valuable component of multi-procedural assessments.

Trapping was the least effective method. In all, we captured one common agouti (*Dasyprocta punctata*), a Hoffmann's two-toed sloth (*Choloepus hoffmanni*) and three common opossums (*Didelphis marsupialis*; Table IV). Solari *et al.* (2001) had more success in trapping Didelphids during a small mammal assessment at the same sites. Our trapping program contained many constraints, and this resulted in lower efficacy for this method. Government regulations, local officials and SPDP regulations discouraged the trapping of Carnivores and game species. Therefore, we selected trap locations and baits to avoid these animals. If we had obtained collection permits and agreements from all stakeholders to trap all species, we believe trapping success would have been much greater and would have resulted in many Carnivore specimens from the area. Trapping can be a valuable tool for assessment and monitoring of mammals (Jones *et al.*, 1996). It provides absolute confirmation of species presence and voucher specimens. Successful trapping requires the cooperation of stakeholders, experienced field personnel, a clear plan and information regarding the behaviors of the species in question (Schemnitz, 1994).

3.3. MONITORING

3.3.1. *Abundance Index*

We propose an abundance index based on data gathered for the occurrence index. To calculate the abundance index, we multiply evidence values from the occurrence index by the number of independent observations of that type of evidence. We base the abundance index on the same point system as for the occurrence index, except that points from interviews with local residents are not included. It follows that evidence which confirms occurrence will have a direct relationship to abundance. We use the tapir example along with an artificial data set to demonstrate the index (Table III). For example, the evidence value for tracks is 5. If we observe tapir tracks on 7 independent occasions at the site under study, the sub-value for the abundance index would be 35. The abundance index sub-values would then be summed to generate an overall abundance index value, which would be 73 for tapirs. This value could be compared to that for the same tapir population at a future time.

For the abundance index to be valid, we must modify the subjective design used for the occurrence index. Proper study design will allow us to estimate the precision of the index and allow for temporal comparisons. The concept of collecting evidence (mammal events) along transects should remain the same, but other statistical validations must first be met. At each site, we first stratify the landscape into habitat types. Within chosen strata, we establish a series of fixed-width transects to provide a density of mammal events. We must assume that all mammal events are located within each sampling area and choose an appropriate transect width. Note that narrow transects may provide insufficient data, while transects that are too wide will result in missed mammal events and prohibitive amounts of effort. In addition, all transects should be of equal width and length. We then place transects randomly within the strata. Each transect must have equal numbers of scent-post stations placed far enough apart to be independent.

The resulting data can only be used to make comparisons of the same species across different time periods. Cross-species comparisons will not be valid because the type and amount of evidence deposited varies among species. Cross-site comparisons will not be valid because differences in vegetation structure, soil type and other parameters will alter the amount of sign deposited and the effort necessary to detect the sign. For comparisons to be most effective, each assessment should be conducted over a short period of time and subsequent assessments, or monitoring, should be conducted during the same time of year. These steps will reduce the variability in the amount of evidence left by each species.

3.4. EVALUATION AND DECISION MAKING

An index of abundance is ‘any measurable correlative of density’ (Caughley, 1977), and indirect indices are based on indirect evidence such as animal sign, vocalizations, etc. of an animal’s presence (Seber, 1982). The abundance index proposed here is a constant-proportion index, where the indirect evidence, or accumulation of mammal events, is proportional to actual abundance. It follows that the greater the number of individuals present at a location, the more mammal events will be recorded. We assume that these mammal events were being deposited by the individuals at a constant rate and quantity, at least throughout the duration of the assessment. A high index number means there was a lot of activity of a species at the site; a low index number means there was little activity.

Indices can be used to compare populations from different locations at the same time or to compare populations from the same location at different times – monitoring (Lancia *et al.*, 1994). Therefore, changes in the index value over time would relate directly to trends in population abundance. Natural resource managers can evaluate trends in relation to development and determine if populations are being affected. To complete the adaptive management cycle, managers must make decisions based on evaluations of the assessment and monitoring data. These decisions include continue monitoring without modification, alter the monitoring protocol, alter the objectives or adapt the management strategy (Dallmeier and Comiskey, 1998; Comiskey *et al.*, 2000).

4. Conclusion

Large mammals exhibit numerous life forms and habits. To be effective, large mammal monitoring programs require a strategy that investigates many elements simultaneously. While this can be a challenging task, it is nonetheless necessary. There is often uncertainty as to which species will be affected by human development of resources, and so the decision regarding which components to monitor is not always clear, particularly in tropical forests and other remote environments where scientists have only recently begun to examine the high diversity of species and interactions.

We may choose instead to monitor indicator species or some component of the environment that relates to the health of the large mammal community, a valid approach that is widely advocated (Noss, 1990, 1999; Howard *et al.*, 1998). But to be effective, we must know what the indicators are and what they indicate (Simberloff, 1998). This requires knowledge and understanding of the ecology of the species in question and their communities, information that is not currently abundant for tropical forests.

The occurrence index and abundance index help close this gap. The indices use a variety of traditional techniques to collect an assortment of evidence relating to all of the species present. As a result, all of the information necessary to assess and monitor the entire large mammal community will be acquired. The indices provide immediate, quality data that lead to better understanding of the ecology of the forests and their large mammal communities.

As we continue to contemplate and test these indices, we inevitably will need to adapt them. We will find that some components work better or are more efficient, that the evidence values will evolve to more precise values and that we may develop additional methodologies. The indices will also guide us to appropriate indicators to improve monitoring programs. We look forward to healthy debate within the scientific community on the utility of these indices to monitor large mammal communities.

Acknowledgments

We extend our deepest appreciation to all those who made this project possible. In particular, we thank Shell Prospecting and Development Peru for its genuine dedication to making development more environmentally responsible. We thank the Smithsonian Institution Monitoring and Assessment of Biodiversity Program for its assistance in editing this manuscript and for managing the project. We thank the anonymous reviewers for their invaluable comments and we thank our local counterparts for their boundless knowledge of the natural history of the region.

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